VOLUME 84 NO. PL1
MARCH 1958
PART 1

JOURNAL of the

Pipeline Division

PROCEEDINGS OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS

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Journal of the

PIPELINE DIVISION

Proceedings of the American Society of Civil Engineers

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Paper 1574 March, 1958 PL 1

Journal of the
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PIPELINE LOCATION SURVEYS

Earl K. Monteith,[1] J.M. ASCE
(Proc. Paper 1574)

INTRODUCTION

A pipeline, like any construction project, must be located on the ground before construction can begin, or all design finished. This process of surveying the route of a proposed pipeline project on the ground is the duty of the locating engineer and will be the subject of this paper.

Purpose

A pipeline survey has several purposes which all must be considered in their proper proportions simultaneously as the survey progresses. These purposes are, first, to pick the most economic route possible and mark it so that construction forces can readily find the route; gather all information necessary for preparation of route maps, showing all properties and surveys crossed by the route; and to gather all data which might be useful to design personnel, and all data needed to acquire right of way and permits to construct the line.

Most Economic Route

The most econimic route for a pipeline depends on several factors but length is obviously one of the most important. The ideal route of any pipeline would be a straight line from source to termination of the line, with no costly construction problems in between, and no right of way which is impossible to acquire. Therefore, the proper starting point of any route location is the straight line between the source of the line and the destination. A line which lets the locating engineer move either end is very rare, as is the case of any transportation problem, so the route must be shifted to avoid any obstacles

Note: Discussion open until August 1, 1958. A postponement of this closing date can be obtained by writing to the ASCE Manager of Technical Publications. Paper 1574 is part of the copyrighted Journal of the Pipeline Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PL 1, March, 1958.

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along the preliminary straight line. From maps available of the area to be covered, such as U.S. Coast & Gedotic Aeronautical Charts, U.S. Geological Survey Control Maps, State Highway Planning Maps, U.S. Forest Service Area Maps, etc., many of the major changes can be made. These consist of cities and towns which must be avoided, extremely rough terrain which can easily be avoided without much lengthening of the route, large lakes or swamps and marshes which can be avoided, etc.

At this point the locating engineer should fly the proposed route if possible, and then start ground investigation at critical points along the route. Urban and Industrial areas must be investigated closely before decision is made on how close to approach them with the route. If aerial photographs are to be used as field and office aid, or for aerial background finished maps of the project, they should be flown after this much work on the general route is completed. If the general 3 mile wide strip is flown at this point, then there is not much chance that more detailed engineering or construction problems or right of way difficulties will force the route far enough afield to leave the pictures. After the aerial photos are studied and the proposed route plotted on them, the locating engineer is ready to go to the field and actually mark the route on the ground by survey and in so doing cover every foot of the route to see that the most economic route is obtained.

Field Location

The field stake-out should proceed as far in advance of construction date as possible, in order that right of way difficulties which cannot be predicted may be dealt with. Many times right of way acquiring may run into problems which can best be handled by avoiding certain tracts of land, but this is a matter for management; the locating engineer can only use this as another control point, and obtain the best route to satisfy the new condition.

Where right of way is clear the locating engineer must pinpoint the route over every foot of line in order to make sure the best route is utilized. Many factors control the most economical over all route: Construction cost, probability of maintenance problems in the future, operational costs, possibility of urban or industrial development, etc.

Once the general route is selected probably the most important points to be pinpointed are the rivers, stream, and drainage feature crossings. These crossings should be picked well in advance of the survey party so that the route will not be unnecessarily lengthened by large angles to hit the picked crossing. All natural drainage features, whether flowing streams or intermittent streams, must be scouted out in order to pick a crossing. The crossing should be one which will provide firm anchor for the pipe, will not require extensive erosion control, and not cause excessive construction cost. A stream crossing where banks are unstable may lead to maintenance problems which are a continuing cost factor far above normal. A river crossing with firm earth banks that are stable and not in a bend that might cut across to a new channel is ideal. Of course, as in all location decisions, the ideal sometimes will not be found without excessive detours which would be prohibitive on initial cost. Therefore, the locating engineer must be familiar with costs to properly evaluate and decide upon the most economical route. Many times the rock present in the banks must also be taken into consideration in picking stream crossings in mountain and rough terrain. Also in tideland or coastal plains areas many times the presence of swampy and marshy areas adjacent

to rivers will control the location of the crossing.

After all major control points, such as towns, lakes, rivers, mountains, etc., are picked, then the connecting route must be covered foot by foot for the many small decisions which, though not of major importance, individually add up over the miles to become the difference between a good and a poor route. These detail factors are many and variable but primarily concern cost of construction and maintenance. The locating engineer must, at all times, visualize the construction equipment in operation and not locate in such a way as to increase construction costs where a small shift, that would not appreciably affect the length of line, might ease the construction problem. A good example of this in rough terrain is the matter of side hill cut. In order to run the many pieces of machinery necessary to construct the pipeline, the right of way must be fairly level in cross section and many times a very minor change of route will eliminate considerable "dozer" work in obtaining a workable right of way. Pipeline equipment can work very steep slopes as long as the cross section of the right of way is level, or nearly so.

Many times, if looked into far enough in advance, large amounts of rock cut, or large swampy, marsh areas can be avoided without major additions to line length. Any terrain which would require special attention or equipment to open a ditch, should be scouted to ascertain if it is economically feasible to go around.

Also, the erosion characteristics of the terrain crossed should be studied and the line located in a position where future erosion will not uncover the line and cause unnecessary maintenance costs.

Railroads, highways, underground cables and other pipelines also bear consideration in picking route. Highways and railroads must, in most cases, be bored and a casing pipe shoved through so as not to interfere in any way with traffic during construction or at any time when future work must be done. This necessitates large "bell-holes" on each side of the roadway for boring machines, etc. Because of this special condition, all roadways should be crossed in "fill" or level spots and not in a "cut" section as any cut just adds to the depth of ditch and "bell-hole" necessary to give proper clearance between the pipeline and the roadway.

Underground cables and existing pipelines will generally be found to have a minimum depth of cover over them, which forces the new line to go under the existing line. For this reason crossings of pipelines and cables should be made at points where the additional depth ditch will not be a special problem. In other words, crossings of such lines should not be made in stream bottoms, under highways or railroads, rock terrain, swamps, marshes, etc., if it can be avoided.

Survey Procedure

After the route is located on the ground it must be properly marked so that construction personnel can readily find the route during construction, and necessary measurements taken so that line maps can be prepared showing the route. Also, special information is needed at all crossings of controlled streams and rivers, railroads, highways, underground cables, federal and state land, and on many privately owned tracts of land where special descriptions are required by the owner before granting right of way.

Marking on Ground

The matter of marking any survey on the ground varies with each company and each engineer running the survey, but the end result is essentially the same. Generally, the center line survey is marked by wooden stakes being driven every 100 or 200 feet with distance station numbers lettered on each stake. All angle points and instrument set up points are marked by a tacked hub and guard stake having the distance station and degree bend, if any, marked on the stake. Flags are left at all instrument points and in all fences and any other prominent place which might help identify the route. Generally, all angle points and instrument points are further preserved by setting two or more reference points far enough away that they will not be destroyed by construction, so that the survey line may be reconstructed at any time. Also, any terrain with a cover growth will have a cleared sight line through it which will always help locate the survey.

Survey Date Required

The cost of a pipeline depends primarily on the length, so the survey must, of course, obtain the length of the line. Also in order to map the line and acquire the right of way, the survey must obtain the length of line across each property, each survey or section, and each county, state or corporate city, etc. Also ties to property corners, section and survey corners, etc., must be made in order to show the route across each tract of land for description in field notes if necessary.

All rivers and streams are controlled by some authority must have special drawing prepared to be submitted in order to get permission to cross. This includes the length and angle of crossing, as well as a profile of the crossing, showing the depth of the pipe below stream bottom, etc. On navigable rivers this must be a true sea level datum profile and must show the stage of the water level at the time the profile was made. Also the profile must extend far enough beyond the banks of the stream to give sufficient data to design the crossing and calculate the amount of earth work which will have to be done. Also the crossing must be tied to some identifying point such as a bridge, stream junction, or other point which the controlling authority can use to locate the crossing.

Highway crossings must have special permit drawings prepared for submission to the proper Highway Department office for permit to cross. This drawing must show a plan and profile of the crossing with sufficient information for the Highway Department to locate the crossing on their own maps. This is usually done by tying to Highway Department Survey Stations numbers, or bridges, culverts, or intersections, as well as showing mileage to nearest town or city.

Permit for railroad crossings must be obtained by special drawings submitted to the railroad company's engineering department, which shows the location of the crossing, its profile, etc., as with the highway drawing. Most railroads have mile posts set along their right of way which make the best identification of the proposed crossing, along with the mileage to the nearest town.

Underground telephone cables and power lines are usually very well marked on the ground by numbered poles or posts which, when shown in

relation to the crossing, give the company controlling the cable sufficient data to locate the proposed crossing.

Federal land, National Forests, State land, land owned by large landowners, and land owned by cities, many times require special drawings which show the complete parcel of land with the proposed route shown in relation to all corners and lines by center line description field notes. To meet this requirement, the survey party must establish the exact boundary of each tract and tie it to the pipeline survey. Where corners have been destroyed in some manner over the years, this sometimes entails considerable work of a land surveying nature.

Miscellaneous Survey Data

The field survey notes should show at all times, the type of terrain crossed, such as rock, sand, clay, hills, flatland, timber, brush, pasture, cultivation, grassland, etc. Also any fact run into in the field which might be of help to the design or planning of the line should be in the field notes. Any local improvements which are pending, such as dams, highways, subdivisions, factories, etc., which in the future might affect the line, should also be noted.

Many liquid lines will require a continuous profile for use in hydraulic design of pumping facilities and valve placement, etc.

Also, many special tracts for pumping stations, valve sites, storage of maintenance equipment, etc. will require location of proper sites and survey for drawings in order to purchase the site and design the facilities required.

SUMMARY

Proper location of pipeline route requires extensive research into all available maps and information; complete aerial and ground reconnaissance of all possible routes; adequate knowledge of construction costs and methods; mature judgment in making all route decisions; and competent field survey procedures. When this all comes from one man you have another field of Civil Engineering in pipeline work, "The Locating Engineer." Route location is not in any way a new field, as our thousands of miles of railroads, highways, power lines will attest, and the Locating Engineer since time immemorial, has been a specialist in the engineering and surveying field, with experience very seldom found in the background of the local land surveyor.

Paper 1575 March, 1958 PL 1

Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

DIGITAL COMPUTERS APPLIED TO PIPELINE DESIGN[a]

Harold E. Thomas[1]
(Proc. Paper 1575)

The ability of an automatic digital electronic computer to perform hundreds of arithmetic and logic operations per second makes it a very efficient tool in solving complex mathematical or engineering problems. Whether or not a tool of such high caliber should be applied to any specific task depends both upon the speed and accuracy required for the results as well as with the frequency the problem is performed. The purpose of a computer then, is to perform both mathematical and logical applications at tremendous speeds without the element of human error entering into the computations.

In order to comprehend the application of a computer to any problem it is necessary to have some understanding of the basic elements of the computer's physical units. A computer of any type consists of five basic elements:

1. input
2. arithmetic unit
3. storage
4. control
5. output

Even a standard desk calculator may be considered analagous to an electronic computer in these five categories. The input is the keyboard, the arithmetic unit is the internal mechanism, the storage is either the operator's brain or the paper on which the results are written, the control lies with the operator, and the output is in the dials.

The specific type of computer I am concerned with here differs primarily from any other type of electronic computer in the characteristic of its storage facility. The storage of this type computer is a magnetic drum (see Diagram 1). This is a cylinder with a sheet of magnetic material wrapped

Note: Discussion open until August 1, 1958. A postponement of this closing date can be obtained by writing to the ASCE Manager of Technical Publications. Paper 1575 is part of the copyrighted Journal of the Pipelines Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PL 1, March, 1958.

a. Before the Committee on Pipeline, Construction Division, ASCE, Dallas, Texas, February, 1956.

1. Pipeline Design Division, Engrg. Dept., El Paso Natural Gas Co., El Paso, Texas.

around its surface. When this drum is made to revolve, bits of information in the form of current pulses can be recorded as magnetic spots in the surface of the drum. Information is recorded as a coded ten digit number, with associated sign, referred to in computer terminology as a "word." This "word" may either be data information or an instruction operation code, which the machine has been designed to interpret as some arithmetic or logic operation. Each "word" may be recalled from drum storage for usage at any time or may be replaced by new information at any time. Each "word" is retained on the drum until a new "word" is recorded in its place. Computers designed by different manufacturers have varying capacities as to the number of "words" which may be recorded on the drum. The general capacity range is between 1000 and 2000 "words."

The term probably heard most often around a computer facility is "programming." Programming is the breaking down of a problem or formula into its simplest arithmetical and logical steps. After the problem is broken down into these steps, the programmer must code them into the language of the machine. Before programming is started, a careful analysis of the problem must be made. The objective of the problem, the limitations of the available computing equipment, how information is to be given, and how results are to be presented must all be very carefully considered. The programming of a problem generally requires more time than it would take to perform the computation manually. For this reason, a calculation to be used as a computer application must be one that is to be repeated many times. The variables or parameters may change for each calculation, but the basic computational procedure must be repetitious. A problem can be programmed with varying degrees of efficiency. More programming time is required to obtain optimum computing speed. Whether or not this additional time should be used depends on the frequency of computation.

In September 1955, El Paso Natural Gas Company placed in operation an IBM Type 650 Magnetic Drum Data-Processing Machine. This machine has a drum storage capacity of 2000 "words." One of the first problems considered as an application for this computer was the pipeline design problem. It was desired to eliminate as much of the tedious manual calculations as possible to give pipeline design engineers more time to study the problem from an engineering standpoint. It was also desired to program into the machine as much control as possible, so the machine would be able to make simple decisions to keep the design within limits specified by the design engineers.

A modified Panhandle Eastern flow equation is employed to compute pressure loss between points in the pipeline system. This flow equation involves numbers to fractional powers and square roots, in addition to the simple arithmetic operations such as addition, subtraction, multiplication and division. These basic operations are built into the machine as standard codes. This made it necessary to program such subroutines as logarithm of A, 10 to the A power, and square root of A, using the four basic arithmetic operations as building blocks to obtain the desired results. These three subroutines along with other subroutines needed in the calculations required approximately 300 words of drum storage.

Using these programmed subroutines as additional tools it was possible to program all the primary routines needed for the calculation of a pipeline system (see Diagram 2).

The pipeline flow calculation computes the pressure loss due to friction between points along the pipeline and also adjusts this pressure with static head conditions effected by the differential elevation between the two points. This routine was programmed in such a manner as to be effective whether computing counterflow or in the same direction as the gas flow. This primary routine required approximately 185 "words" of drum storage, as well as the incorporation of all the subroutines previously programmed.

The loop line calculation uses the same modified Panhandle Eastern flow equation but varies the parameters. The purpose of the routine is to compute the number of miles of pipeline of specified size paralleling the existing system to meet pressure conditions between two points on the pipeline. The pressures at these two points may have been computed on a previous calculation pass or may have been specified at the beginning of the problem. This routine requires approximately 140 "words" of drum storage.

Emperical polynomials have been derived for the horsepower vs. compression ratio curves for a reciprocating compressor engine. Using these polynomials and a computed or specified compression ratio, this routine computes horsepower requirements at a reciprocating compressor station. The fuel used is computed and added to the flowing volume on the discharge side to give flowing volume on the suction side of the station. The centrifugal horsepower formula was programmed in the same manner to obtain the horsepower and fuel requirements at a centrifugal compressor station. These routines required approximately 280 "words" of drum storage.

Control routines are needed to integrate the usage of these calculation routines. These routines also check the computations at various points to ascertain if the system is still within specified limits. At any time a limit is exceeded the machine will either consult an instruction card to determine in what manner to proceed, or in the case of a predetermined decision, will proceed as had been specified in the program (see Diagram 3). These routines control the output of the completed results into punched cards. All control routines require approximately 250 "words" of drum storage.

The programming of all these routines fills approximately 1300 of the 2000 "words" capacity of the drum. This leaves 700 "words" available for pipeline data storage. These 700 "words" were divided into seventy 10 "word" blocks. Each point on the pipeline where a pressure computation is required such as a takeoff volume point or elevation correction point, uses one of these blocks. The data which must be supplied for each point are pipeline code, milepost, elevation, pipe data, allowable working pressure of pipe, and tap volume. In addition, two "words" must be left open for the computed pressure and volume of gas flowing through that particular line section.

Each compressor station, whether reciprocating or centrifugal, requires two of these ten "word" blocks of data. Data which must be specified are milepost, elevation, discharge pressure limit, installed sea level horsepower, pipe data, horsepower elevation correction, tap volume and compression ratio. Data computed to fill in the blocks are brake horsepower, discharge pressure, volume compressed, sea level horsepower required, suction pressure and fuel.

One block is used for the input of initial flow conditions (pipeline efficiency, specific gravity, flowing temperature, and pressure base). Each time any one of these factors changes along the pipeline a new block is required. A typical pipeline might consist of 59 line section points and 5 compressor stations with the flow conditions block completing the 700 available "words" (70 ten "word"

blocks) to fill the entire drum to capacity.

With the drum filled to capacity, the only means of exercising any further control is by an instruction card (see Diagram 3). An instruction card is read by the machine each time the computation, proceeding counterflow, reaches the discharge of a compressor station successfully and is within specified limits. This instruction card, prepared previous to the computation by the design engineer, is effective then for the compressor station just reached and the pipeline upstream to the discharge of the next station. In case the specified compression ratio of the station required more horsepower than has been specified, the instruction card is consulted to see if additional horsepower is desired to maintain this specified ratio or if a new ratio should be determined from the specified installed horsepower or horsepower limit. The station computation can then be completed. The pipeline flow calculation then proceeds and computes pressure along the pipeline to the discharge of the upstream station. When the point on the discharge of the upstream station has been computed, the machine checks to see if the allowable working pressure or discharge limit pressure has been exceeded at any point on the pipeline in that section. If the pressure has been exceeded the instruction card is consulted. This card specifies whether loop line should be added in that section or a new suction pressure computed at the downstream station and horsepower added.

If loop line is desired, the design engineer must specify, on the instruction card, the milepost where loop is to start and the pipe size of the loop line to be added. The machine then makes a direct flow run and a counterflow run as specified on the instruction card to pull conditions in that section within specified limits.

To run a complete pipeline study, the first step is to load into the drum from cards, the 1300 words of programmed calculation instructions. At the full card reading rate of 200 cards per minute and four "words" per card, this loading takes approximately 1 minute and 40 seconds. The second step is to load the pipeline data. One card has the full information for one data point to fill one of the ten "word" blocks. Since 70 of these blocks is the maximum number allowable, loading pipeline data could not take more than 21 seconds. The pipeline data cards are followed by cards specifying starting pressure and volume conditions. The instruction cards prepared by the engineer are placed in the input card feed to be consulted as the computation progresses up the pipeline. The computing time, then, varies depending upon the number of line sections and the computations necessary to stay within the limit conditions specified. At the conclusion of the calculation, all data, complete with pressures, volumes, required horsepower, fuel and other necessary items are stored on the drum. The punch-out routine then becomes effective and punches these results into cards. The resulting punched cards are run through a tabulating machine which prints the results in the form required by the design engineer. Any subsequent pipeline studies may be calculated without loading the programmed calculation instructions, since these remain on the drum until replaced by different type calculations.

A typical mainline study required about ten minutes computing time. It is estimated that this same study done manually would require two weeks of computing for one man. Of course considerable time is required to lay out the pipeline in the manner required by the computer. For existing pipelines, however, this layout can be performed once and is valid until loop line or

horsepower is added. When this is done, minor modifications to the layout data keep it up to date. A proposed or new line must be laid out completely, with surveyed mileposts and elevation given. This type of layout should require approximately an hour and a half for one man.

To summarize, it has been found that this computing facility is a tremendous aid to the pipeline design engineer, eliminating complex manual computation with its chances of human error, giving more time for engineering thought, with a speed which makes it possible to look at many different studies to select the most desirable design. Only the application of a computer to the design of a gas transmission line has been considered here. Liquid products and water pipelines might be applied in a similar manner. In addition, the transformation of pipeline survey notes to coordinate data is another machine application. Any computational problem which is repetitious in nature might be a computer application, giving more time for creative engineering.

Diagram 1

COMPONENT SCHEMATIC OF MAGNETIC DRUM ELECTRONIC COMPUTER

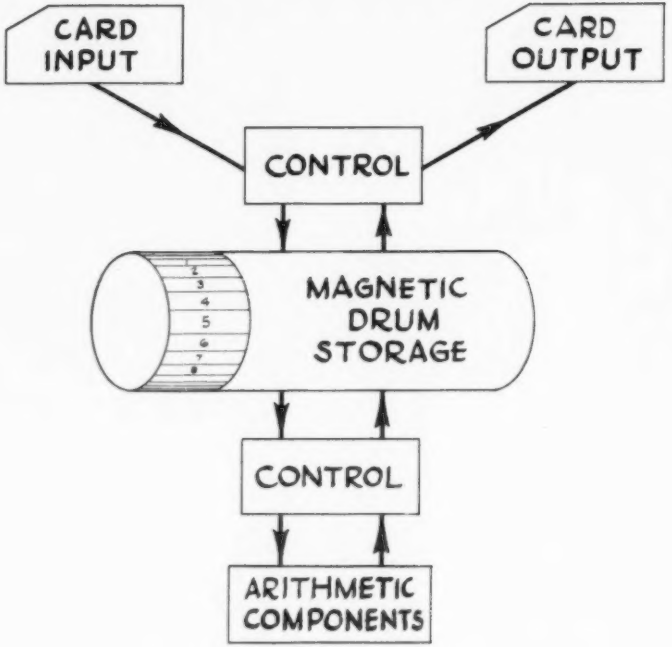


Diagram 2

PIPELINE DESIGN CALCULATION PROGRAMMING BUILD-UP

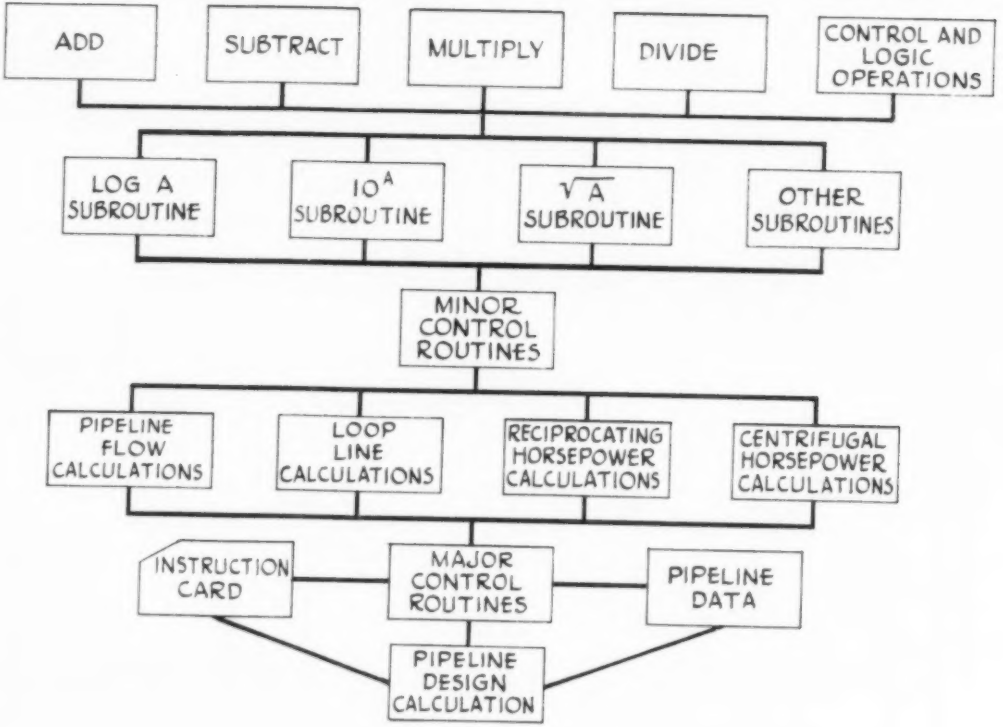
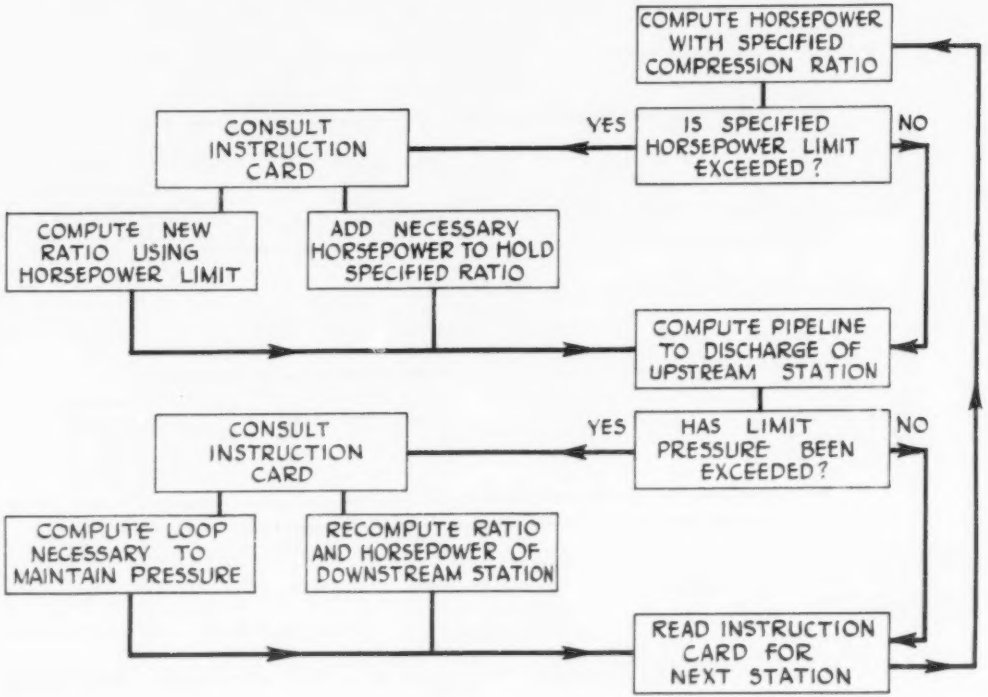


Diagram 3

PIPELINE DESIGN CALCULATION CONTROL SCHEMATIC


COMPUTE HORSEPOWER WITH SPECIFIED COMPRESSION RATIO
IS SPECIFIED HORSEPOWER LIMIT EXCEEDED ?
YES
NO
CONSULT INSTRUCTION CARD
COMPUTE NEW RATIO USING HORSEPOWER LIMIT
ADD NECESSARY HORSEPOWER TO HOLD SPECIFIED RATIO
COMPUTE PIPELINE TO DISCHARGE OF UPSTREAM STATION
HAS LIMIT PRESSURE BEEN EXCEEDED?
YES
NO
CONSULT INSTRUCTION CARD
COMPUTE LOOP NECESSARY TO MAINTAIN PRESSURE
RECOMPUTE RATIO AND HORSEPOWER OF DOWNSTREAM STATION
READ INSTRUCTION CARD FOR NEXT STATION

Paper 1577 March, 1958 PL 1

Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

WATER DISTRIBUTION PROBLEMS SOLVED BY NETWORK CALCULATORS[a]

L. M. Haupt[1]
(Proc. Paper 1577)

The responses of all physical systems are defined by equations that are similar in form. Therefore, it is possible to "set up" an electrical network that will exactly represent a hydraulic system and the quantities read with instruments in the electrical system will truly represent the analogous quantities in the hydraulic system.

An a.c. (alternating current) network calculator (or analyzer) is an analogue computer. It is made up of a large number of adjustable, calibrated electric circuits that may be connected into any desired network. Quantities such as voltages, currents, power, etc. may conveniently be read in any part of the network from a metering console or desk. Although normally used for the study of electrical transmission and distribution problems, it can also be used for both compressible and incompressible fluid distribution problems. The use of such a computer tends to eliminate personal errors and saves many man-hours of labor.

In the electric network the algebraic sum of the electric flow (current) to a junction is zero. Also, the algebraic sum of the electric pressures (voltages) around any closed circuit is zero. These are exactly analogious to flow and pressure drops respectively in fluid systems.

In the electric system the pressure drop is directly proportional to the flow through that unit. The resistance, which is defined as the ratio of the pressure drop to the flow, is a constant. In an incompressible fluid system, the pressure drop is proportional to the 1.85 power of the flow and the corresponding resistance to the 0.85 power of the flow

$$V = R_0 I^{1.85} \quad (1)$$

$$R = R_0 I^{0.85} \quad (2)$$

Note: Discussion open until August 1, 1958. A postponement of this closing date can be obtained by writing to the ASCE Manager of Technical Publications. Paper 1577 is part of the copyrighted Journal of the Pipeline Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. PL 1, March, 1958.

a. Paper presented at a meeting of the American Society of Civil Engineers, February 24-28, 1958, Chicago, Ill.

1. Prof. of electrical eng., A&M College of Texas, College Station, Tex., and supervisor of the A-C Network Calculator, Texas A&M Research Foundation.

where

V is the pressure drop
I is the flow
R is the "resistance"
R_0 is a constant that depends on the size, length, roughness factor, and scale factors.

Studies have been made of hydraulic systems in the following manner:

(1) An electrical network is assembled whereby each pipe section is represented by a calibrated resistor and each source (pumping station, standpipe, etc.) is represented by an electric generator.
(2) A scale factor is selected so that the electric currents and voltages analogous to the hydraulic system may be within the range of the laboratory. For example, one ampere may represent one million gallons per day and one volt may represent a head of one foot.
(3) Calculations are made of the pressure drop in each section of pipe with the hydraulic flow equivalent to one ampere. This is the value of R_0 referred to above.
(4) Initial values of resistance are set in the network. These may be arbitrarily set at any value whatsoever. The initial setting in no way affects the solution.
(5) After the initial values of resistances are set in the electric system, adjustment of the sources and circuits that control the output are made until the desired conditions of input and output are met. The flow in each resistance is measured. The resistance of each section is then calculated by Eq. (2) above. These calculations are greatly simplified by use of the slide rule described below.
(6) A value of resistance between the calculated value and the previous value is set for each line section. This will change the given input and output conditions and will make necessary a readjustment of the sources and circuits that control these quantities. After this is done, the flow in each line section is again read and the calculations and adjustments repeated. Usually after the third adjustment, the accuracy of the results is such that no further adjustments are necessary.

In making studies of hydraulic systems, it is usually preferable to read all pressures with reference to some arbitrary point rather than absolute values. This may be with respect to the highest elevation on the system or with reference to the elevation of some other point. All of this is shown in the example given below.

Some time ago it was found that tungsten filaments in an evacuated tube follow very closely the relationship of Eq. (1). The increase in resistance with current is due to the change in temperature of the filament. Fluid flow analysers using this type of special resistance unit have been built and are in commercial operation.

Ordinary incandescent lamps behave exactly as the special tungsten tubes. When a lamp is connected across the secondary of a variable auto-transformer, the lamp-transformer unit may be made to reflect various resistances into the network, and these reflected resistances will retain the non-linear characteristics of the lamp above.

A number of these "non-linear" type of resistances have been used in conjunction with a number of standard calibrated resistances on commercial

studies. These "non-linear" resistances were set in the following manner. The first three steps are the same as above.

(7) An initial setting was made on the transformer so that the reflected resistance of the lamp is the value of R_0 calculated above.
(8) After the electric system has been adjusted to meet the given input and output conditions, the voltage drop across the "non-linear" impedance that corresponds to the measured current is calculated by Eq. (1). If the measured voltage drop differs from the calculated value, the proper adjustment is made of the transformer setting. These calculations are also simplified by the slide rule described below.

It was found that if the proper lamp size and the proper scale factor were used, little or no adjustment was needed on the "non-linear" resistance other than the initial setting. The lamp may be seen to glow when these conditions are met. As the pressure-flow relationship was always checked with the slide rule before taking data, the accuracy is not affected if the wrong size lamp is used. The time to obtain a solution is decreased if proper selections are made as no subsequent adjustments will be needed.

The electric power loss of any circuit may be read directly. This is the product of the flow in and the pressure drop across that circuit. By means of an adjustable multiplier this loss may be read in kilowatts, horsepower, or any other desirable unit. This affords a very rapid analysis of the system. Those circuits having high power losses are the critical lines in the system.

The special slide rule referred to above was designed for use on hydraulic systems. The scales are logarithmic with the lower and upper frame scales proportional to the 0.85 and 1.85 power of the slide scale.

Calculations for the calibrated resistances (Procedure 5) are made by using the slide and the lower frame scales. The index of the slide is set opposite the value of R_0 and the value of resistance is read opposite the value of measured flow set on the slide.

Calculations for "non-linear" resistance (Procedure 7) are made using the slide and the upper frame scales. The index of the slide is set opposite the value for R_0 (on upper frame scale). The value for pressure drop is read opposite the value of actual flow set on the slide.

Compressible fluid distribution problems may be solved in a similar manner, except the "resistance" also varies inversely as the average pressure. Because of the ease of reading voltages (analogous to pressure) anywhere in the system, the work and time involved in solving this type of problem is not increased greatly over the solution of incompressible fluid networks.

A slide rule designed especially for compressible fluid problems would be similar to the one described above except the slide itself would have two scales. The upper slide scale would be the same as the upper frame scale. This additional scale could be used for dividing by the average pressure.

D. C. (direct current) network calculators can be used as readily as the a.c. calculator. Special purpose analogue computers, both d.c. and a.c. have been designed for this type of problem.

Example

Note: This example shows only a part of a much larger system. All head

pressures are measured with respect to another stand pipe G1 not shown on this diagram.

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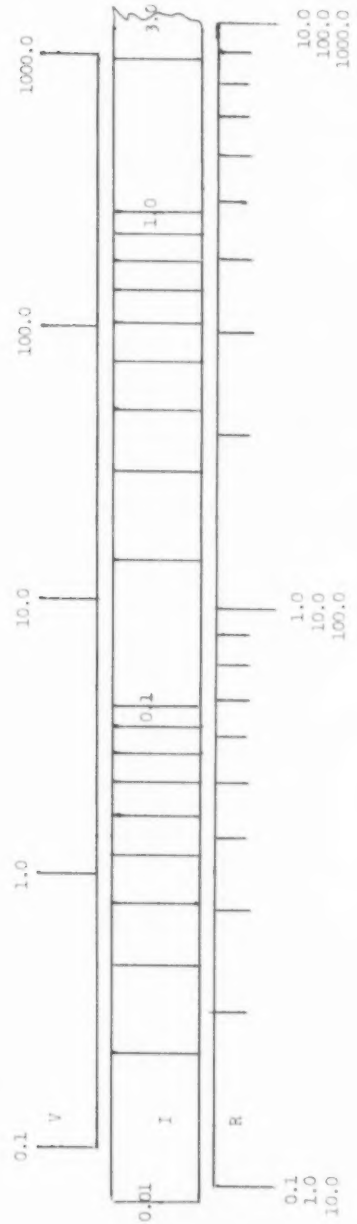
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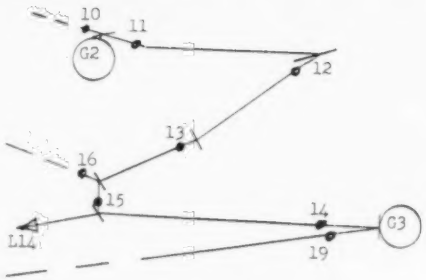

Cir. No.	Length	Diameter	Roughness Factor	R_o
11	6800'	1.0"	110	12.2
12	4200'	1.0"	110	7.6
13	3400'	1.0"	110	6.1
14	9500'	1.33"	103	4.8
15	950'	1.33"	103	0.5

1 volt is equivalent to one foot head
1 ampere is equivalent to 10 million gallons per day.

	I_1	R_1	I_2	R_2	I_3	R_3	I_4	R_4	Power	h_L	Q MGD	H_L Feet
G1							.96			0	9.60	1167*
G2							1.96			-18	19.60	1149*
G3							.75			10	7.50	117*
11	0	0	-.098	~~120.0~~ 40.0	-.049	~~60.0~~ 48.0	-.030	42.7	negligible		.30	
12	0	0	-.098	~~75.0~~ 30.0	-.049	~~41.0~~ 37.0	-.030	26.4	negligible	-17.7	.30	1149.3
13	0	0	-.098	~~60.0~~ 20.0	-.049	~~33.0~~ 26.0	-.030	21.5	negligible	-17.3	.30	1149.7
14	.236	96.0	.255	~~104.0~~ 99.0	.228	~~96.0~~ 97.0	.228	96.0	5.0		2.28	
15	.218	8.9	.232	~~9.6~~ 9.2	.207	~~8.6~~ 8.8	.206	8.6	.4		2.06	
L14	.18*		.018*		.018*		.018*			-15.4	.18*	1151.6

I_1 is an assumed value. Values of R_2 and R_3 set are shown in script.

*given data

The power measurements indicate that the line #14 is the critical one so far as this part of the system is concerned.

Journal of the
PIPELINE DIVISION
Proceedings of the American Society of Civil Engineers

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Note: Paper 1578 is part of the copyrighted Journal of the Pipeline Division, Proceedings of the American Society of Civil Engineers, Vol. 84, PL 1, March, 1958.

PREDICTION OF SURGE PRESSURES IN OIL PIPELINES[a]

Closure by Robert D. Kersten and Edwin J. Waller

ROBERT D. KERSTEN,[1] A.M. ASCE, and EDWIN J. WALLER,[2] A.M. ASCE.—The writers are grateful for Mr. Paynter's review of this paper and for the interest which has moved him to suggest an additional approach for the application of analog computer techniques to this problem. The lucid logical deduction of the physical concepts of the dynamic analogy of electrical and hydraulic systems by the discusser(1) has long been recognized. Principal application of these concepts has been to transient (i.e. waterhammer) phenomena.

However, it was the intent of the authors to outline a method of analysis of the steady-state (i.e. periodic forced vibratory) surge phenomena based on a fundamental mathematical approach. The results of this analysis were recognized as being mathematically identical with the electric wave equations for the alternating-current transmission line. Thus, the circuit analysis techniques already well developed by the electrical engineer could be applied directly to pipeline engineering problems. A mathematical proof now supports the prior logical reasoning regarding the so-called hydraulic-electrical analogy.

The details of the mathematical derivation have been presented in other publications.(2,3) It was the purpose of this paper to demonstrate the validity of the theoretical solution through application to an actual field-scale pumping pipeline system. More specifically, the experiments discussed by the writers were designed to evaluate in a quantitative manner the response of the pipeline system rather than leave this response as a symbol in a casual block diagram such as the discusser's Figs. 1 to 6. Such diagrams are quite informative and the operations indicated by those diagrams can be carried out only when the correct electrical impedances are placed in the analog computer. This can only be done after certain quantitative experiments are carried out on models or prototypes. Prior work included model studies. This paper relates the results of experiments for the response of the prototype. As a result of this experimental work, the simplifying assumptions made in the solution of the differential equations involved in this problem have been verified. In addition, the applicability of the fundamental principles to a field-scale reciprocating pump has been shown.

Electronic computer techniques can now be applied with complete confidence. It is well recognized that experimental work is not a prerequisite to computer studies. However, as in any realistic research and development

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a. Proc. Paper 1195, March, 1957, by Robert D. Kersten and Edwin J. Waller.

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2. Prof. of Civ. Eng., Oklahoma State Univ., Stillwater, Okla.

program, prototype verification as opposed to model studies—including analogs—must be undertaken. That this has been done at this stage of the program simply means that the value of any analog or digital computer studies—past, present or future—has been greatly enhanced.

A recent publication[3] by one of the authors gives a short resume of the theoretical and experimental work done at Oklahoma State University in the general field of pressure surges. More detailed reporting will follow in future publications.

Correction

Please note that Eq. (5) of the original paper should have the factor ρ_{rho} in the denominator.

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3. "Pressure Surges in Pipelines" by E. J. Waller. ASME Paper No. 57Pet16, Sept. 1957.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1449 is identified as 1449 (HY 6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1957.

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c. Discussion of several papers, grouped by divisions.

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